



(19) Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11) EP 0 807 424 A2

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
19.11.1997 Bulletin 1997/47

(51) Int. Cl.<sup>6</sup>: A61F 2/06

(21) Application number: 97202436.8

(22) Date of filing: 27.10.1992

(84) Designated Contracting States:  
BE CH DE FR GB IT LI NL

- Frantzen, John J.  
San Jose, California 95132 (US)
- Hartigan, William M.  
Fremont, California 94555 (US)

(30) Priority: 28.10.1991 US 783558

(74) Representative:  
McLeish, Nicholas Alastair Maxwell et al  
Boult Wade Tennant  
27 Furnival Street  
London EC4A 1PQ (GB)

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:  
92309822.2 / 0 540 290

Remarks:

This application was filed on 06 - 08 - 1997 as a divisional application to the application mentioned under INID code 62.

(71) Applicant:

ADVANCED CARDIOVASCULAR SYSTEMS, INC.  
Santa Clara California 95052-8167 (US)

(72) Inventors:

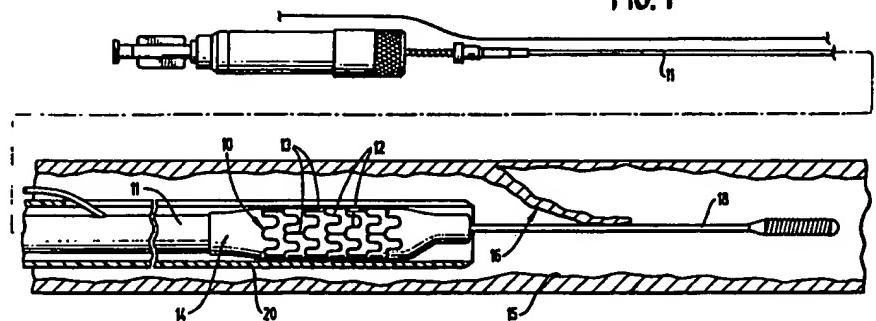
- Lau, Lili P.  
Cupertino, California 95014 (US)

### (54) Expandable stents and method for making same

(57) The invention is directed to an expandable stent (10) for implantation in a body lumen, such as an artery, and a method for making it from a single length of tubing. The stent (10) consists of a plurality of radially expandable cylindrical elements (12) generally aligned on a common axis and interconnected by one or more interconnective elements (13). The individual radially expandable cylindrical elements (12) consist of ribbon-like material disposed in an undulating pattern. The stents (10) are made by coating a length of tubing (21)

with an etchant-resistant material and then selectively removing portions of the coating to form a pattern for the stent (10) on the tubing (21) to expose the portions of the tubing to be removed. This may be done by machine-controlled activation and relative positioning of a laser (24) in conjunction with the coated tubing (21). After the patterning of the tubing (21), the stent (10) is formed by removing exposed portions of the tubing (21) by an etching process.

FIG. 1



EP 0 807 424 A2

## Description

This invention relates to expandable endoprostheses devices, generally called stents, which are adapted to be implanted into a patient's body lumen, such as blood vessel, to maintain the patency thereof. These devices are very useful in the treatment of atherosclerotic stenosis in blood vessels.

Stents are generally tubular shaped devices which function to hold open a segment of a blood vessel or other anatomical lumen. They are particularly suitable for use to support and hold back a dissected arterial lining which can occlude the fluid passageway therethrough.

Further details of prior art stents can be found in U.S. Patent 3,868,956 (Alfidi *et al.*); U.S. Patent 4,512,338 (Balko *et al.*); U.S. Patent 4,553,545 (Maass *et al.*); U.S. Patent 4,733,665 (Palmaz); U.S. Patent 4,762,128 (Rosenbluth); U.S. Patent 4,800,882 (Gianturco); U.S. Patent 4,856,516 (Hillstead); and U.S. Patent 4,886,062 (Wiktor).

Various means have been described to deliver and implant stents. One method frequently described for delivering a stent to a desired intraluminal location includes mounting the expandable stent on an expandable member, such as a balloon, provided on the distal end of an intravascular catheter, advancing the catheter to the desired location within the patient's body lumen, inflating the balloon on the catheter to expand the stent into a permanent expanded condition and then deflating the balloon and removing the catheter. One of the difficulties encountered using prior stents involved maintaining the radial rigidity needed to hold open a body lumen while at the same time maintaining the longitudinal flexibility of the stent to facilitate its delivery.

What has been needed and heretofore unavailable is a stent which has a high degree of flexibility so that it can be advanced through tortuous passageways and can be readily expanded and yet have the mechanical strength to hold open the body lumen into which it is expanded.

One prior art device which goes somewhat towards addressing this problem is described in US-A-4,994,071. The described stent includes a trunk portion constructed from a series of generally parallel oriented loops interconnected by a series of half-hitch connections which extend along an axial dimension. In combination the series of loops form a generally cylindrical lattice or matrix.

The present invention is directed to an expandable stent which is relatively flexible along its longitudinal axis to facilitate delivery through tortuous body lumens, but which is stiff and stable enough radially in an expanded condition to maintain the patency of a body lumen such as an artery when implanted therein.

According to a first aspect of the present invention there is provided a longitudinally flexible stent formed from an elongated tubular member and comprising a plurality of cylindrically shaped elements which are

independently expandable in the radial direction and which are connected to one another by interconnecting elements so as to be generally aligned on a common longitudinal axis such that, other than at an end of the stent, each cylindrically shaped element has two adjacent cylindrically shaped elements spaced in opposite axial directions, the or each interconnecting element connecting one of said cylindrically shaped elements to one of said adjacent cylindrically shaped elements being circumferentially displaced from the or each interconnecting element connecting said cylindrically shaped element to the other of said adjacent cylindrically shaped elements.

Thus the stent of the invention includes a plurality of radially expandable cylindrical elements which are relatively independent in their ability to expand and to flex relative to one another. The individual radially expandable cylindrical elements of the stent are preferably dimensioned so as to be longitudinally shorter than their own diameters. Interconnecting elements or struts extend between adjacent cylindrical elements and provide increased stability and are preferably positioned to prevent warping of the stent upon the expansion thereof. The resulting stent structure is a series of radially expandable cylindrical elements which are spaced longitudinally close enough so that small dissections in the wall of a body lumen may be pressed back into position against the luminal wall, but not so close as to compromise the longitudinal flexibility of the stent.

The individual cylindrical elements may rotate slightly relative to adjacent cylindrical elements without significant deformation, cumulatively giving a stent which is flexible along its length and about its longitudinal axis but which is still very stiff in the radial direction in order to resist collapse.

A stent embodying features of the invention can be readily delivered to the desired luminal location by mounting it on an expandable member of a delivery catheter, for example a balloon, and passing the catheter-stent assembly through the body lumen to the implantation site. A variety of means for securing the stent to the expandable member on the catheter for delivery to the desired location are available. It is presently preferred to compress the stent onto the balloon. Other means to secure the stent to the balloon include providing ridges or collars on the inflatable member to restrain lateral movement, or using bioresorbable temporary adhesives.

The presently preferred structure for the expandable cylindrical elements which form the stents of the present invention is to have a generally circumferential undulating pattern, e.g. serpentine. The transverse cross-section of the undulating component of the cylindrical element is relatively small and preferably has an aspect ratio of about two to one to about 0.5 to one. A one to one aspect ratio has been found particularly suitable. The open reticulated structure of the stent allows for the perfusion of blood over a large portion of the arterial wall which can improve the healing and repair of

a damaged arterial lining.

The radial expansion of the expandable cylinder deforms the undulating pattern thereof similar to changes in a waveform which result from decreasing the waveform's amplitude and the frequency. Preferably, the undulating patterns of the individual cylindrical structures are in phase with each other in order to prevent the contraction of the stent along its length when it is expanded. The cylindrical structures of the stent are plastically deformed when expanded (except with NiTi alloys) so that the stent will remain in the expanded condition and, therefore, they must be sufficiently rigid when expanded to prevent the collapse thereof in use. With superelastic NiTi alloys, the expansion occurs when the stress of compression is removed so as to allow the phase transformation from austenite back to martensite and as a result the expansion of the stent.

The elongated elements which interconnect adjacent cylindrical elements should have a transverse cross-section similar to the transverse dimensions of the undulating components of the expandable cylindrical elements. The interconnecting elements may be formed in a unitary structure with the expandable cylindrical elements from the same intermediate product, such as a tubular element, or they may be formed independently and connected by suitable means, such as by welding or by mechanically securing the ends of the interconnecting elements to the ends of the expandable cylindrical elements. Preferably, all of the interconnecting elements of a stent are joined at either the peaks or the valleys of the undulating structure of the cylindrical elements which form the stent. In this manner there is no shortening of the stent upon expansion.

The number and location of elements interconnecting adjacent cylindrical elements can be varied in order to develop the desired longitudinal flexibility in the stent structure both in the unexpanded as well as the expanded condition. These properties are important to minimize alteration of the natural physiology of the body lumen into which the stent is implanted and to maintain the compliance of the body lumen which is internally supported by the stent. Generally, the greater the longitudinal flexibility of the stent, the easier and the more safely it can be delivered to the implantation site.

In a presently preferred arrangement the stent is conveniently and easily formed by coating stainless steel hypotubing with a material resistant to chemical etching, and then removing portions of the coating to expose portions of underlying tubing which are to be removed to develop the desired stent structure. The exposed portions of the tubing are removed by chemically etching from the tubing exterior leaving the coated portion of the tubing material in the desired pattern of the stent structure. The etching process develops smooth openings in the tubing wall without burrs or other artifacts which are characteristic of mechanical or laser machining processes in the small sized products contemplated. Moreover, a computer controlled laser patterning process to remove the chemical resistive

coating makes photolithography technology adaptable to the manufacture of these small products. The forming of a mask in the extremely small sizes needed to make the small stents of the invention would be a most difficult task. A plurality of stents can be formed from one length of hypotubing by repeating the stent pattern and providing small webs or tabs to interconnect the stents. After the etching process, the stents can be separated by severing the small webs or tabs which connect them.

Other features and advantages of the present invention will become more apparent from the following detailed description of the invention, when taken in conjunction with the accompanying exemplary drawings.

FIG. 1 is an elevational view, partially in section, of a stent embodying features of the invention which is mounted on a delivery catheter and disposed within a damaged artery.

FIG. 2 is an elevational view, partially in section, similar to that shown in FIG. 1 wherein the stent is expanded within a damaged artery, pressing the damaged lining against the arterial wall.

FIG. 3 is an elevational view, partially in section showing the expanded stent within the artery after withdrawal of the delivery catheter.

FIG. 4 is a perspective view of a stent embodying features of the invention in an unexpanded state, with one end of the stent being shown in an exploded view to illustrate the details thereof.

FIG. 5 is a plan view of a flattened section of a stent of the invention which illustrates the undulating pattern of the stent shown in FIG. 4.

FIG. 6 is a schematic representation of equipment for selectively removing coating applied to tubing in the manufacturing of the stents of the present invention.

FIGS. 7 and 10 are perspective views schematically illustrating various configurations of interconnective element placement between the radially expandable cylindrical elements of the stent.

FIG. 11 is a plan view of a flattened section of a stent illustrating an alternate undulating pattern in the expandable cylindrical elements of the stent which are out of phase.

FIG. 1 illustrates a stent 10 incorporating features of the invention which is mounted onto a delivery catheter 11. The stent generally comprises a plurality of radially expandable cylindrical elements 12 disposed generally coaxially and interconnected by elements 13 disposed between adjacent cylindrical elements. The delivery catheter 11 has an expandable portion or balloon 14 for expanding the stent 10 within an artery 15. The artery 15, as shown in FIG. 1, has a dissected lining 16 which has occluded a portion of the arterial passage-way.

The delivery catheter 11 onto which the stent 10 is mounted, is essentially the same as a conventional balloon dilatation catheter used for angioplasty procedures. The balloon 14 may be formed of suitable materials such as polyethylene, polyethylene terephthalate, polyvinyl chloride, nylon and ionomers such as

Surlyn™ manufactured by the Polymer Products Division of the Du Pont Company. Other polymers may also be used. In order for the stent 10 to remain in place on the balloon 14 during delivery to the site of the damage within the artery 15, the stent 10 is compressed onto the balloon. A retractable protective delivery sleeve 20 as described in US-A-5,507,768 and entitled "Stent Delivery System for use with Body Lumens in treating Endo-Arterial Prosthesis" may be provided to further ensure that the stent stays in place on the expandable portion of the delivery catheter 11 and prevent abrasion of the body lumen by the open surface of the stent 10 during delivery to the desired arterial location. Other means for securing the stent 10 onto the balloon 14 may also be used, such as providing collars or ridges on the ends of the working portion, i.e. the cylindrical portion, of the balloon.

Each radially expandable cylindrical element 12 of the stent 10 may be independently expanded. Therefore, the balloon 14 may be provided with an inflated shape other than cylindrical, e.g. tapered, to facilitate implantation of the stent 10 in a variety of body lumen shapes.

In a preferred embodiment, the delivery of the stent 10 is accomplished in the following manner. The stent 10 is first mounted onto the inflatable balloon 14 on the distal extremity of the delivery catheter 11. The balloon 14 is slightly inflated to secure the stent 10 onto the exterior of the balloon. The catheter-stent assembly is introduced within the patient's vasculature in a conventional Seldinger technique through a guiding catheter (not shown). A guidewire 18 is disposed across the damaged arterial section with the detached or dissected lining 16 and then the catheter-stent assembly is advanced over a guidewire 18 within the artery 15 until the stent 10 is directly under the detached lining 16. The balloon 14 of the catheter is expanded, expanding the stent 10 against the artery 15, which is illustrated in FIG. 2. While not shown in the drawing, the artery 15 is preferably expanded slightly by the expansion of the stent 10 to seat or otherwise fix the stent 10 to prevent movement. In some circumstances during the treatment of stenotic portions of an artery, the artery may have to be expanded considerably in order to facilitate passage of blood or other fluid therethrough.

The stent 10 serves to hold open the artery 15 after the catheter 11 is withdrawn, as illustrated by FIG. 3. Due to the formation of the stent 10 from an elongated tubular member, the undulating component of the cylindrical elements of the stent 10 is relatively flat in transverse cross-section, so that when the stent is expanded, the cylindrical elements are pressed into the wall of the artery 15 and as a result do not interfere with the blood flow through the artery 15. The cylindrical elements 12 of stent 10 which are pressed into the wall of the artery 15 will eventually be covered with endothelial cell growth which further minimizes blood flow interference. The undulating portion of the cylindrical sections 12 provide good tacking characteristics to prevent stent move-

ment within the artery. Furthermore, the closely spaced cylindrical elements 12 at regular intervals provide uniform support for the wall of the artery 15, and consequently are well adapted to tack up and hold in place small flaps or dissections in the wall of the artery 15 as illustrated in FIGS. 2 and 3.

FIG. 4 is an enlarged perspective view of the stent 10 shown in FIG. 1 with one end of the stent shown in an exploded view to illustrate in greater detail placement of interconnecting elements 13 between adjacent radially expandable cylindrical elements 12. Each pair of the interconnecting elements 13 on one side of a cylindrical element 12 are preferably placed to achieve maximum flexibility for a stent. In the embodiment shown in FIG. 4 the stent 10 has three interconnecting elements 13 between adjacent radially expandable cylindrical elements 12 which are 120 degrees apart. Each pair of interconnecting elements 13 on one end of a cylindrical element 12 are offset radially 60 degrees from the pair on the other side of the cylindrical element. The alternation of the interconnecting elements results in a stent which is longitudinally flexible in essentially all directions. Various configurations for the placement of interconnecting elements are possible, and several examples are illustrated schematically in FIGS. 7-10. However, as previously mentioned, all of the interconnecting elements of an individual stent should be secured to either the peaks or valleys of the undulating structural elements in order to prevent shortening of the stent during the expansion thereof.

FIG. 10 illustrates a stent of the present invention wherein three interconnecting elements 13 are disposed between radially expandable cylindrical elements 12. The interconnecting elements 13 are distributed radially around the circumference of the stent at a 120 degree spacing. Disposing four or more interconnecting elements between adjacent cylindrical elements 12 will generally give rise to the same considerations discussed above for two and three interconnecting elements.

The properties of the stent 10 may also be varied by alteration of the undulating pattern of the cylindrical elements 12. FIG. 11 illustrates an alternative stent structure in which the cylindrical elements are in serpentine patterns but out of phase with adjacent cylindrical elements. The particular pattern and how many undulations per unit of length around the circumference of the cylindrical element 12, or the amplitude of the undulations, are chosen to fill particular mechanical requirements for the stent such as radial stiffness.

The number of undulations may also be varied to accommodate placement of interconnecting elements 13, e.g. at the peaks of the undulations or along the sides of the undulations as shown in FIGS. 5 and 11.

The stent 10 of the present invention can be made in many ways. However, the preferred method of making the stent is to coat a thin-walled tubular member, such as stainless steel hypotubing with a material which is resistive to chemical etchants and then to remove por-

tions of the coating to expose underlying hypotubing which is to be removed but to leave coated portions of the hypotubing in the desired pattern for the stent so that subsequent etching will remove the exposed portions of the metallic tubing, but will leave relatively untouched the portions of the metallic tubing which are to form the stent. The coated portion of the metallic tube is in the desired shape for the stent. An etching process avoids the necessity of removing burrs or slag inherent in conventional or laser machine processes. It is preferred to remove the etchant-resistive material by means of a machine-controlled laser as illustrated schematically in FIG. 6.

A coating is applied to a length of tubing which, when cured is resistive to chemical etchants. "Blue Photoresist" made by the Shipley Company in San Jose, California, is an example of a suitable commercially available photolithographic coating. The coating is preferably applied by electrophoretic deposition.

To ensure that the surface finish is reasonably uniform, one of the electrodes used for the electrochemical polishing is a doughnut-shaped electrode which is placed about the central portion of the tubular member.

The tubing may be made of any suitable biocompatible material such as stainless steel, titanium, tantalum, superelastic NiTi alloys and even high strength thermoplastic polymers. The stent diameter is very small, so the tubing from which it is made must necessarily also have a small diameter. Typically the stent has an outer diameter on the order of about 1.5mm (0.06 inch) in the unexpanded condition, the same outer diameter of the hypotubing from which it is made, and can be expanded to an outer diameter of 2.5mm (0.1 inch) or more. The wall thickness of the hypotubing is about 0.076 mm (0.003 inch). In the instance when the stent is plastic, it has to be heated within the arterial site where the stent is expanded to facilitate the expansion of the stent. Once expanded, it is cooled to retain its expanded state. The stent may be conveniently heated by heating the fluid within the balloon or by heating the balloon directly by a suitable system such as disclosed in US-A-5,114,423 entitled "Dilation Catheter Assembly with Heated Balloon".

The stent may also be made of materials such as superelastic NiTi alloys such as described in US-A-5,411,476 entitled "Super-Elastic Guiding Member for Advancing Catheter".

In this case the stent would be formed full size but deformed (e.g. compressed) into a small diameter onto the balloon of the delivery catheter to facilitate transfer to a desired intraluminal site. The stress induced by the deformation transforms the stent from a martensite phase to an austenite phase and upon release of the force, when the stent reaches the desired intraluminal location, allows the stent to expand due to the transformation back to the martensite phase.

Referring to FIG. 6, the coated tubing 21 is put in a rotatable collet fixture 22 of a machine controlled apparatus 23 for positioning the tubing 21 relative to a laser

24. According to machine-encoded instructions, the tubing 21 is rotated and moved longitudinally relative to the laser 24 which is also machine controlled. The laser selectively removes the etchant-resistive coating on the tubing by ablation and a pattern is formed such that the surface of the tube that is to be removed by a subsequent chemical etching process is exposed. The surface of the tube is therefore left coated in the discrete pattern of the finished stent.

10 A presently preferred system for removing the coating on the tubing includes the use of an 80 watt CO<sub>2</sub> laser, such as Coherent Model 44, in pulse mode (0.3 mS pulse length); 48 mA key current and 48 W key power with 0.75 W average power; at 100 Hz; Anorad FR=10; 1680 Pa; (12.5 Torr); with no assist gas. Low pressure air is directed through the fine focus head to ensure that no vapor contacts the lens. The assist gas jet assembly on the laser unit may be removed to allow a closer proximity of the fine focus head and the collet fixture. Optimum focus is set at the surface of the tubing. Cured photoresist coating readily absorbs the energy of the CO<sub>2</sub> wavelength, so that it can be readily removed by the laser. A coated 9.1 cm (4 inch) length of 1.5 mm (0.06 inch) stainless steel tubing is preferred and four stents can be patterned on the length of tubing. Three tabs or webs between stents provide good handling characteristics for the tubing after the etching process.

15 The process of patterning the resistive coating on the stent is automated except for loading and unloading the length of tubing. Referring again to FIG. 6 it may be done, for example, using a CNC opposing collet fixture 22 for axial rotation of the length of tubing, in conjunction with the CNC X/Y table 25 to move the length of tubing axially relative to a machine controlled laser as described. The entire space between collets can be patterned using the CO<sub>2</sub> laser set-up of the foregoing example. The program for control of the apparatus is dependent on the particular configuration used and the pattern to be ablated in the coating, but is otherwise conventional.

20 This process makes possible the application of present photolithography technology in manufacturing the stents. While there is presently no practical way to mask and expose a tubular photoresist-coated part of the small size required for making intravascular stents, the foregoing steps eliminate the need for conventional masking techniques.

25 After the coating is thus selectively ablated, the tubing is removed from the collet fixture 22. Next, wax such as ThermoCote N-4 is heated to preferably just above its melting point, and inserted into the tubing under vacuum or pressure. After the wax has solidified upon cooling, it is reheated below its melting point to allow softening, and a small diameter stainless steel shaft is inserted into the softened wax to provide support. The tubing is then etched chemically in a conventional manner. After cutting the tabs connecting the stents any surface roughness or debris from the tabs is removed. The stents are preferably electrochemically polished in an

acidic aqueous solution such as a solution of ELECTRO-GLO #300, sold by ELECTRO-GLO CO., Inc., in Chicago, IL, which is a mixture of sulfuric acid, carboxylic acids, phosphates, corrosion inhibitors and a biodegradable surface active agent. The bath temperature is maintained at about 43 to 57 degrees centigrade (about 110-135 degrees F.) and the current density is about 0.06 to 2.3 amps/cm<sup>2</sup> (about 0.4 to about 1.5 amps per in<sup>2</sup>). Cathode to anode area should be at least about two to one. The stents may be further treated if desired, for example by applying a biocompatible coating.

While the invention has been illustrated and described herein in terms of its use as an intravascular stent, it will be apparent to those skilled in the art that the stent can be used in other instances such as to expand prostatic urethras in cases of prostate hyperplasia. Other modifications and improvements can be made without departing from the scope of the invention.

#### Claims

1. A longitudinally flexible stent, comprising a plurality of cylindrically shaped elements which are independently expandable in the radial direction and which are interconnected so as to be generally aligned on a common axis.
2. The stent of claim 1 wherein the cylindrically shaped members are adapted to retain their expanded condition upon the expansion thereof.
3. The stent of claim 1 or claim 2, wherein the radially expandable cylindrical elements in an unexpanded condition have a length less than the diameter thereof.
4. The stent of any preceding claim wherein each radially expandable cylindrical element is formed of a structural member having transverse dimensions with an aspect ratio of less than two to one, with the structural member formed in an undulating pattern and disposed about the longitudinal axis of the stent.
5. The stent of claim 4 wherein the structural member is formed of a biocompatible material selected from the group consisting of stainless steel, tungsten, tantalum, superelastic NiTi alloys and thermoplastic polymers.
6. The stent of any preceding claim wherein the cylindrically shaped members have interconnective elements at one end thereof which are in axial alignment with interconnecting elements on the opposite end of the cylindrical elements.
7. The stent of claim 6 wherein each interconnecting element at one end of a cylindrical element is circumferentially displaced from an interconnective element on the opposite end of the cylindrical element.
8. The stent of claim 6 or claim 7, wherein the circumferential displacement of the interconnecting elements is of equal magnitude.
9. The stent of any preceding claim, wherein there are up to four interconnective elements disposed between adjacent radially expandable cylindrical elements.
10. The stent of any preceding claim, wherein the radially expandable cylindrical elements and the interconnecting elements are made of the same material.
11. The stent of claim 9 wherein the stent is formed from a single piece of tubing.
12. The stent of any preceding claim, wherein the cylindrical elements are formed of structural members in an undulating pattern.
13. The stent of claim 12 wherein the undulating patterns of the structural members of the stent are in phase.
14. The stent of claim 13 wherein the connecting elements of the stent are all connected to either the peaks or the valleys of the undulating structural members.
15. The process of making a stent which includes the steps of:
  - a) applying a coating resistive to chemical etching to a length of tubing;
  - b) selectively removing portions of the resistive coating to expose sections of the tubing; and
  - c) removing exposed portions of the tubing.
16. The process of claim 15 wherein a plurality of stents are made from a single piece of tubing.
17. The process of claim 15 or claim 16 wherein the stent is made from a biocompatible material selected from the group consisting of polymers, stainless steel, titanium, superelastic NiTi alloys and tantalum.
18. The process of any of claims 15 to 17, wherein the coating is applied by electrophoretic deposition.
19. The stent of claim 1 wherein the stent is coated with a biocompatible coating.
20. A method for making open reticulated tubular structure, comprising the steps of:

- a) providing a discrete length of thin walled tubing;
  - b) forming a resistive coating onto the exterior of the tubing;
  - c) selectively removing portions of the resistive coating on the exterior of the tubing to leave the desired pattern of the complete open reticulated tubular structure coated with resistive coating and to expose portion of the tubing to be removed; and
  - d) removing the exposed portions of the tubing.
21. The method of claim 20 wherein the exposed portions of the tubing is removed by etching. 15
22. The method of claim 20 wherein the selective removal of the resistive coating is accomplished by machine controlled relative movement of the tubing and a laser. 20
23. The method of claim 22 wherein the laser used to selectively remove the resistive coating emits a particular wavelength of light which is readily absorbable by said coating. 25
24. The method of claim 22 or claim 23 wherein the laser is a CO<sub>2</sub> gas laser.
25. The method of any of claims 20 to 24 wherein the resistive coating used is a photolithographic chemically resistive coating. 30
26. A kit comprising:
- a) an elongated stent delivery catheter having proximal and distal extremities, and an expandable member on the distal extremity; and
  - b) a longitudinally flexible stent which is adapted to a slidably mounted on to the expandable member of said catheter and which comprises a plurality of cylindrical elements which are independently expandable in the radial direction and which are interconnected so as to be generally aligned on a common axis.

35

40

45

50

55

FIG. 1

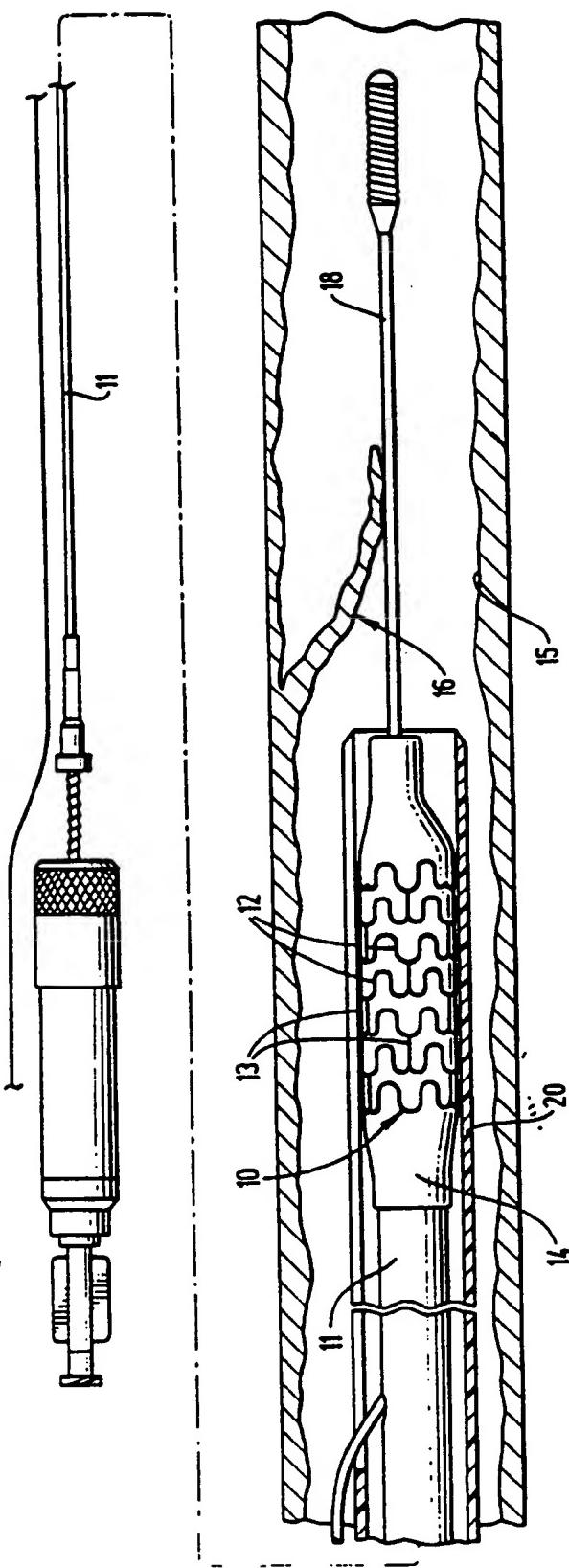


FIG. 2

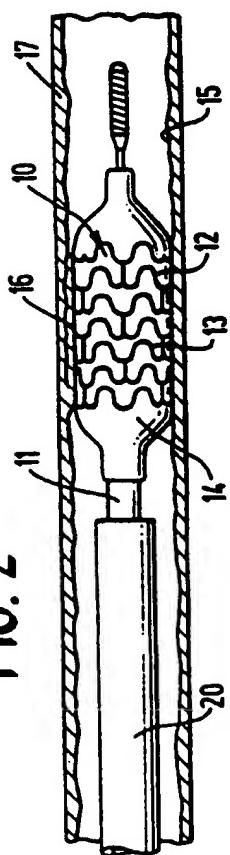
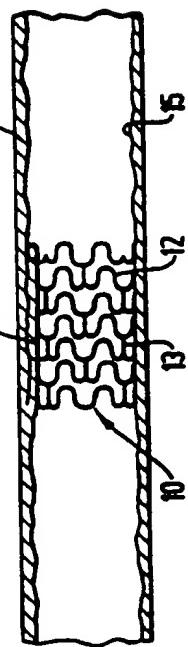


FIG. 3



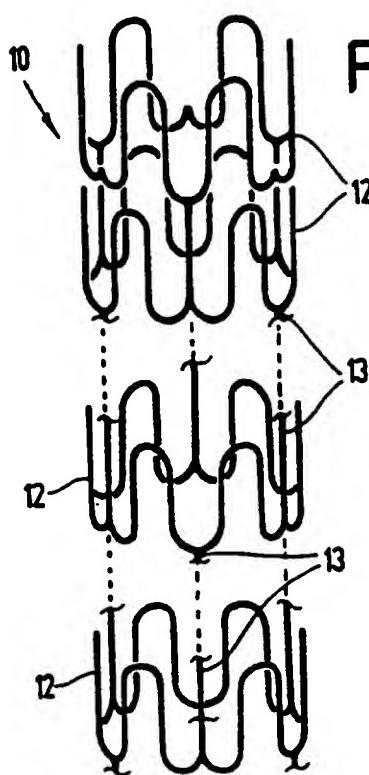


FIG. 4

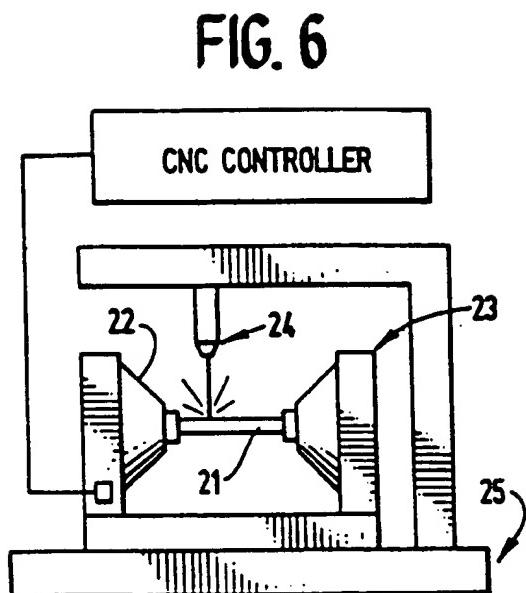


FIG. 6

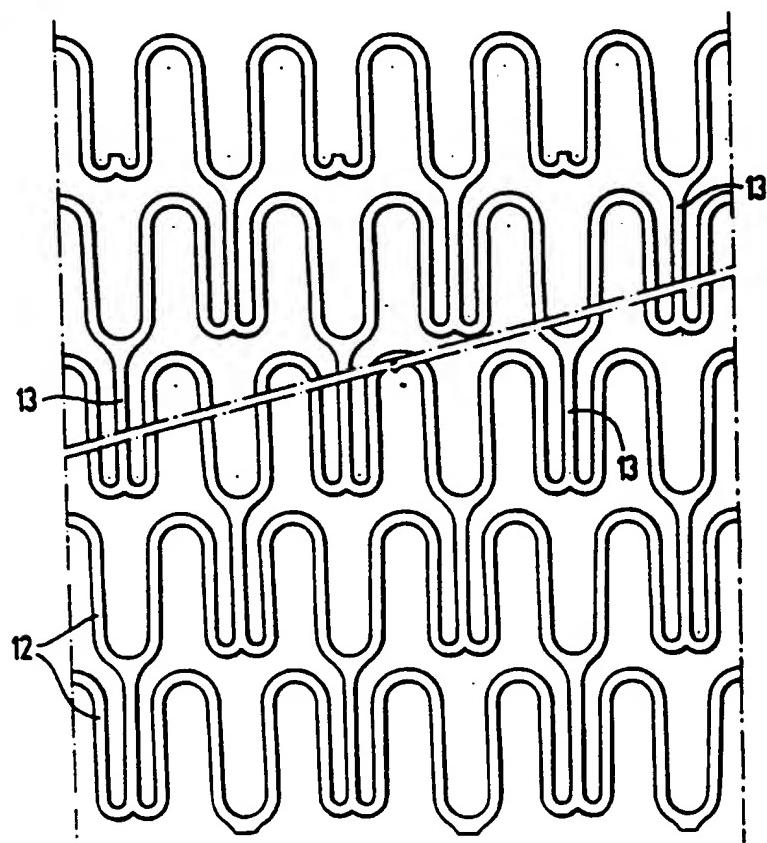
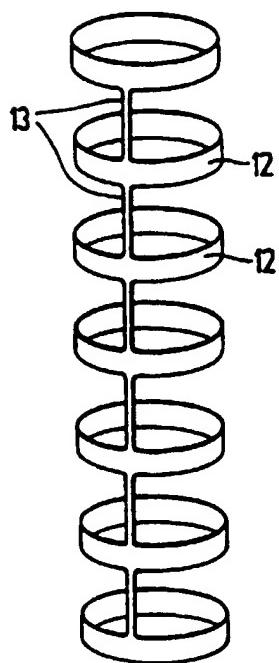
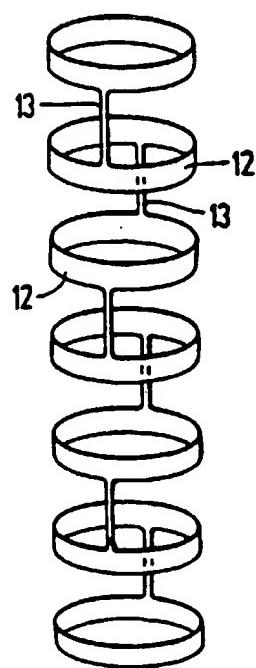


FIG. 5

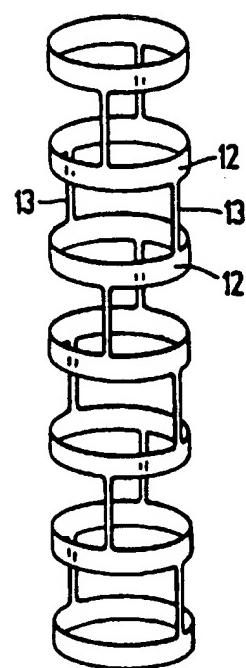
**FIG. 7**



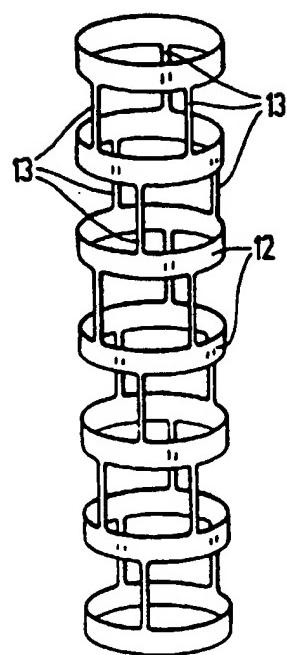
**FIG. 8**



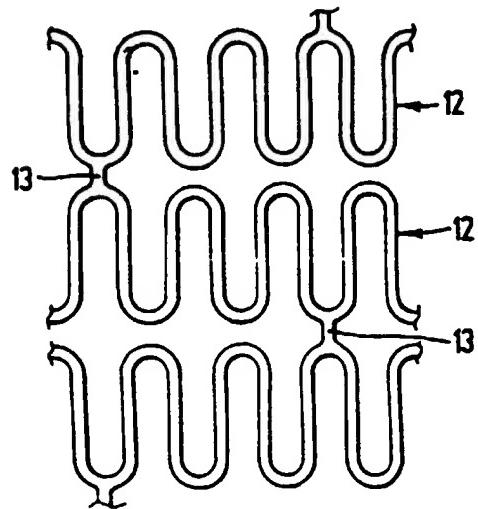
**FIG. 9**



**FIG. 10**



**FIG. 11**





(19)

Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 807 424 A3

(12)

# **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:  
29.12.1997 Bulletin 1997/52

(51) Int. Cl.<sup>6</sup>: A61F 2/06

(43) Date of publication A2:  
19.11.1997 Bulletin 1997/47

(21) Application number: 97202436.8

**(22) Date of filing: 27.10.1992**

**(84) Designated Contracting States:**  
**BE CH DE FR GB IT LI NL**

(30) Priority: 28.10.1991 US 783558

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:  
**92309822.2 / 0 540 290**

(71) Applicant:  
**ADVANCED CARDIOVASCULAR SYSTEMS, INC.**  
**Santa Clara California 95052-8167 (US)**

**(72) Inventors:**

- **Lau, Lilip**  
Cupertino, California 95014 (US)
  - **Frantzen, John J.**  
San Jose, California 95132 (US)
  - **Hartigan, William M.**  
Fremont, California 94555 (US)

(74) Representative:

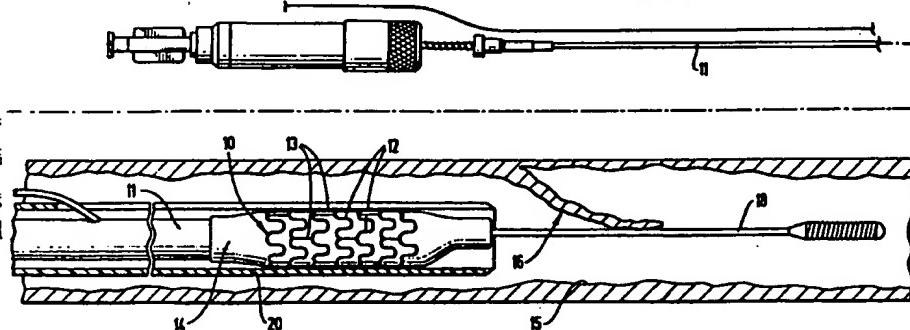
**McLeish, Nicholas Alistair Maxwell et al  
Bout Wade Tennant  
27 Furnival Street  
London EC4A 1PQ (GB)**

**(54) Expandable stents and method for making same**

(57) The invention is directed to an expandable stent (10) for implantation in a body lumen, such as an artery, and a method for making it from a single length of tubing. The stent (10) consists of a plurality of radially expandable cylindrical elements (12) generally aligned on a common axis and interconnected by one or more interconnective elements (13). The individual radially expandable cylindrical elements (12) consist of ribbon-like material disposed in an undulating pattern. The stents (10) are made by coating a length of tubing (21)

with an etchant-resistant material and then selectively removing portions of the coating to form a pattern for the stent (10) on the tubing (21) to expose the portions of the tubing to be removed. This may be done by machine-controlled activation and relative positioning of a laser (24) in conjunction with the coated tubing (21). After the patterning of the tubing (21), the stent (10) is formed by removing exposed portions of the tubing (21) by an etching process.

**FIG. 1**





European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number

EP 97 20 2436

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
P,X	US 5 135 536 A (R.A. HILLSTEAD) * the whole document *	1-4,6, 10,12,26	A61F2/06
P,A	WO 92 09246 A (NUMED) * abstract; figures *	1-5,12	
D,Y	US 4 733 665 A (J.C. PALMAZ) * column 7, line 14 - line 20; figures 2A,2B *	15-18, 20-23,25	
Y	EP 0 338 816 A (KAWASAKI STEEL CORPORATION) * abstract; figures 3,17 * * column 7, line 44 - line 48 *	15-18, 20-23,25	
Y	EP 0 361 192 A (SIEMENS) * column 4, line 23 - line 38 *	18	
A	EP 0 062 300 A (FRITZ WITTIG) * page 4, line 1 - line 29 *	15,20-22	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	US 4 767 418 A (W.D. DEININGER) * column 3, line 48 - column 4, line 10 *	15,17, 20,21,25	A61F C23F
A	WO 91 07139 A (I. LEONARD) * page 3, line 8 - page 4, line 3 * * page 4, line 16 - line 22 *	20-22	
D,A	US 4 762 128 A (R.F. ROSENBLUTH) * column 10, line 36 - line 47; figure 4 *	15-17, 20,21	
A	EP 0 407 951 A (SHIPLEY COMPANY) * abstract *	18	
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	23 October 1997	Wolf, C	
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			



(19)

Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11)

EP 0 807 424 B1

(12)

## EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention  
of the grant of the patent:  
04.08.1999 Bulletin 1999/31

(51) Int. Cl.<sup>6</sup>: A61F 2/06

(21) Application number: 97202436.8

(22) Date of filing: 27.10.1992

## (54) Expandable stents

Aufweitbare Stents  
Stents expansibles

(84) Designated Contracting States:  
BE CH DE FR GB IT LI NL

- Frantzen, John J.  
San Jose, California 95132 (US)
- Hartigan, William M.  
Fremont, California 94555 (US)

(30) Priority: 28.10.1991 US 783558

(74) Representative:  
McLeish, Nicholas Alistair Maxwell et al  
Boutt Wade Tennant  
27 Furnival Street  
London EC4A 1PQ (GB)

(43) Date of publication of application:  
19.11.1997 Bulletin 1997/47

## (56) References cited:

EP-A- 0 062 300	EP-A- 0 338 816
EP-A- 0 361 192	EP-A- 0 407 951
WO-A-91/07139	WO-A-92/09246
US-A- 4 733 665	US-A- 4 762 128
US-A- 4 767 418	US-A- 4 994 071
US-A- 5 135 536	

(62) Document number(s) of the earlier application(s) in  
accordance with Art. 76 EPC:  
92309822.2 / 0 540 290

(73) Proprietor:  
ADVANCED CARDIOVASCULAR SYSTEMS, INC.  
Santa Clara California 95052-8167 (US)

(72) Inventors:  
• Lau, Lillip  
Cupertino, California 95014 (US)

EP 0 807 424 B1

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

**Description**

[0001] This invention relates to expandable endoprostheses devices, generally called stents, which are adapted to be implanted into a patient's body lumen, such as blood vessel, to maintain the patency thereof. These devices are very useful in the treatment of atherosclerotic stenosis in blood vessels.

[0002] Stents are generally tubular shaped devices which function to hold open a segment of a blood vessel or other anatomical lumen. They are particularly suitable for use to support and hold back a dissected arterial lining which can occlude the fluid passageway therethrough.

[0003] Further details of prior art stents can be found in U.S. Patent 3,868,956 (Alfidi et al.); U.S. Patent 4,512,338 (Balko et al.); U.S. Patent 4,553,545 (Maass et al.); U.S. Patent 4,733,665 (Palmaz); U.S. Patent 4,762,128 (Rosenbluth); U.S. Patent 4,800,882 (Gianturco); U.S. Patent 4,856,516 (Hillstead); and U.S. Patent 4,886,062 (Wiktor).

[0004] Various means have been described to deliver and implant stents. One method frequently described for delivering a stent to a desired intraluminal location includes mounting the expandable stent on an expandable member, such as a balloon, provided on the distal end of an intravascular catheter, advancing the catheter to the desired location within the patient's body lumen, inflating the balloon on the catheter to expand the stent into a permanent expanded condition and then deflating the balloon and removing the catheter. One of the difficulties encountered using prior stents involved maintaining the radial rigidity needed to hold open a body lumen while at the same time maintaining the longitudinal flexibility of the stent to facilitate its delivery.

[0005] What has been needed and heretofore unavailable is a stent which has a high degree of flexibility so that it can be advanced through tortuous passageways and can be readily expanded and yet have the mechanical strength to hold open the body lumen into which it is expanded.

[0006] One prior art device which goes somewhat towards addressing this problem is described in US-A-4,994,071. The described stent includes a trunk portion constructed from a series of generally parallel oriented loops interconnected by a series of half-hitch connections which extend along an axial dimension. In combination the series of loops form a generally cylindrical lattice or matrix.

[0007] The present invention is directed to an expandable stent which is relatively flexible along its longitudinal axis to facilitate delivery through tortuous body lumens, but which is stiff and stable enough radially in an expanded condition to maintain the patency of a body lumen such as an artery when implanted therein.

[0008] According to a first aspect of the present invention there is provided a longitudinally flexible stent comprising a plurality of cylindrically shaped elements

5 having an undulating pattern of peaks and valleys, the cylindrically shaped elements being independently expandable in the radial direction and generally aligned on a common longitudinal axis such that, other than at an end of the stent, each cylindrically shaped element has two adjacent cylindrically shaped elements spaced in opposite axial directions, the undulating pattern of each of said cylindrically shaped elements being out of phase with the undulating pattern of each of said adjacent cylindrically shaped elements and each of said cylindrically shaped elements being interconnected to one of said adjacent cylindrically shaped elements at a location circumferentially displaced from the location at which said cylindrically shaped element is interconnected to the other of said adjacent cylindrically shaped elements.

[0009] Thus in a preferred embodiment of the invention the stent includes a plurality of radially expandable cylindrical elements which are relatively independent in their ability to expand and to flex relative to one another. The individual radially expandable cylindrical elements of the stent are preferably dimensioned so as to be longitudinally shorter than their own diameters. Interconnecting elements or struts extend between adjacent cylindrical elements and provide increased stability and are preferably positioned to prevent warping of the stent upon the expansion thereof. The resulting stent structure is a series of radially expandable cylindrical elements which are spaced longitudinally close enough so that small dissections in the wall of a body lumen may be pressed back into position against the luminal wall, but not so close as to compromise the longitudinal flexibility of the stent. The individual cylindrical elements may rotate slightly relative to adjacent cylindrical elements without significant deformation, cumulatively giving a stent which is flexible along its length and about its longitudinal axis but which is still very stiff in the radial direction in order to resist collapse.

[0010] A stent embodying features of the invention 40 can be readily delivered to the desired luminal location by mounting it on an expandable member of a delivery catheter, for example a balloon, and passing the catheter-stent assembly through the body lumen to the implantation site. A variety of means for securing the stent to the expandable member on the catheter for delivery to the desired location are available. It is presently preferred to compress the stent onto the balloon. Other means to secure the stent to the balloon include providing ridges or collars on the inflatable member to restrain lateral movement, or using bioresorbable temporary adhesives.

[0011] The expandable cylindrical elements which form the stent of the present invention have a generally circumferential undulating pattern, e.g. serpentine. The transverse cross-section of the undulating component of the cylindrical element is relatively small and preferably has an aspect ratio of about two to one to about 0.5 to one. A one to one aspect ratio has been found partic-

ularly suitable. The open reticulated structure of the stent allows for the perfusion of blood over a large portion of the arterial wall which can improve the healing and repair of a damaged arterial lining.

[0012] The radial expansion of the expandable cylinder deforms the undulating pattern thereof similar to changes in a waveform which result from decreasing the waveform's amplitude and the frequency.

[0013] The cylindrical structures of the stent are plastically deformed when expanded (except with NiTi alloys) so that the stent will remain in the expanded condition and, therefore, they must be sufficiently rigid when expanded to prevent the collapse thereof in use. With superelastic NiTi alloys, the expansion occurs when the stress of compression is removed so as to allow the phase transformation from austenite back to martensite and as a result the expansion of the stent.

[0014] The elongated elements which interconnect adjacent cylindrical elements should have a transverse cross-section similar to the transverse dimensions of the undulating components of the expandable cylindrical elements. The interconnecting elements may be formed in a unitary structure with the expandable cylindrical elements from the same intermediate product, such as a tubular element, or they may be formed independently and connected by suitable means, such as by welding or by mechanically securing the ends of the interconnecting elements to the ends of the expandable cylindrical elements. Preferably, all of the interconnecting elements of a stent are joined at either the peaks or the valleys of the undulating structure of the cylindrical elements which form the stent. In this manner there is no shortening of the stent upon expansion.

[0015] The number and location of elements interconnecting adjacent cylindrical elements can be varied in order to develop the desired longitudinal flexibility in the stent structure both in the unexpanded as well as the expanded condition. These properties are important to minimize alteration of the natural physiology of the body lumen into which the stent is implanted and to maintain the compliance of the body lumen which is internally supported by the stent. Generally, the greater the longitudinal flexibility of the stent, the easier and the more safely it can be delivered to the implantation site.

[0016] In a presently preferred arrangement the stent is conveniently and easily formed by coating stainless steel hypotubing with a material resistant to chemical etching, and then removing portions of the coating to expose portions of underlying tubing which are to be removed to develop the desired stent structure. The exposed portions of the tubing are removed by chemically etching from the tubing exterior leaving the coated portion of the tubing material in the desired pattern of the stent structure. The etching process develops smooth openings in the tubing wall without burrs or other artifacts which are characteristic of mechanical or laser machining processes in the small sized products contemplated. Moreover, a computer controlled laser

patterning process to remove the chemical resistive coating makes photolithography technology adaptable to the manufacture of these small products. The forming of a mask in the extremely small sizes needed to make the small stents of the invention would be a most difficult task. A plurality of stents can be formed from one length of hypotubing by repeating the stent pattern and providing small webs or tabs to interconnect the stents. After the etching process, the stents can be separated by severing the small webs or tabs which connect them.

[0017] Other features and advantages of the present invention will become more apparent from the following detailed description of the invention, when taken in conjunction with the accompanying exemplary drawings. However, reference is made to the fact that Figure 10 is the only figure showing a stent according the features of claim 1.

FIG. 1 is an elevational view, partially in section, of a stent which is mounted on a delivery catheter and disposed within a damaged artery.

FIG. 2 is an elevational view, partially in section, similar to that shown in FIG. 1 wherein the stent is expanded within a damaged artery, pressing the damaged lining against the arterial wall.

FIG. 3 is an elevational view, partially in section showing the expanded stent within the artery after withdrawal of the delivery catheter.

FIG. 4 is a perspective view of a stent in an unexpanded state, with one end of the stent being shown in an exploded view to illustrate the details thereof.

FIG. 5 is a plan view of a flattened section of a stent which illustrates the undulating pattern of the stent shown in FIG. 4.

FIG. 6 is a schematic representation of equipment for selectively removing coating applied to tubing in the manufacturing of the stents of the present invention.

FIGS. 7 to 9 are perspective views schematically illustrating various configurations of interconnective element placement between the radially expandable cylindrical elements of the stent.

FIG. 10 is a plan view of a flattened section of a stent in which the undulating patterns of alternate expandable cylindrical elements are out of phase.

[0018] FIG. 1 illustrates a stent 10 which is mounted onto a delivery catheter 11. The stent generally comprises a plurality of radially expandable cylindrical elements 12 disposed generally coaxially and

interconnected by elements 13 disposed between adjacent cylindrical elements. The delivery catheter 11 has an expandable portion or balloon 14 for expanding the stent 10 within an artery 15. The artery 15, as shown in FIG. 1, has a dissected lining 16 which has occluded a portion of the arterial passageway.

[0019] The delivery catheter 11 onto which the stent 10 is mounted, is essentially the same as a conventional balloon dilatation catheter used for angioplasty procedures. The balloon 14 may be formed of suitable materials such as polyethylene, polyethylene terephthalate, polyvinyl chloride, nylon and ionomers such as Surlyn™ manufactured by the Polymer Products Division of the Du Pont Company. Other polymers may also be used. In order for the stent 10 to remain in place on the balloon 14 during delivery to the site of the damage within the artery 15, the stent 10 is compressed onto the balloon. A retractable protective delivery sleeve 20 as described in US-A-5,507,768 and entitled "Stent Delivery System for use with Body Lumens in treating Endo-Arterial Prosthesis" may be provided to further ensure that the stent stays in place on the expandable portion of the delivery catheter 11 and prevent abrasion of the body lumen by the open surface of the stent 10 during delivery to the desired arterial location. Other means for securing the stent 10 onto the balloon 14 may also be used, such as providing collars or ridges on the ends of the working portion, i.e. the cylindrical portion, of the balloon.

[0020] Each radially expandable cylindrical element 12 of the stent 10 may be independently expanded. Therefore, the balloon 14 may be provided with an inflated shape other than cylindrical, e.g. tapered, to facilitate implantation of the stent 10 in a variety of body lumen shapes.

[0021] In a preferred embodiment, the delivery of the stent 10 is accomplished in the following manner. The stent 10 is first mounted onto the inflatable balloon 14 on the distal extremity of the delivery catheter 11. The balloon 14 is slightly inflated to secure the stent 10 onto the exterior of the balloon. The catheter-stent assembly is introduced within the patient's vasculature in a conventional Seldinger technique through a guiding catheter (not shown). A guidewire 18 is disposed across the damaged arterial section with the detached or dissected lining 16 and then the catheter-stent assembly is advanced over a guidewire 18 within the artery 15 until the stent 10 is directly under the detached lining 16. The balloon 14 of the catheter is expanded, expanding the stent 10 against the artery 15, which is illustrated in FIG. 2. While not shown in the drawing, the artery 15 is preferably expanded slightly by the expansion of the stent 10 to seat or otherwise fix the stent 10 to prevent movement. In some circumstances during the treatment of stenotic portions of an artery, the artery may have to be expanded considerably in order to facilitate passage of blood or other fluid therethrough.

[0022] The stent 10 serves to hold open the artery 15

after the catheter 11 is withdrawn, as illustrated by FIG. 3. Due to the formation of the stent 10 from an elongated tubular member, the undulating component of the cylindrical elements of the stent 10 is relatively flat in transverse cross-section, so that when the stent is expanded, the cylindrical elements are pressed into the wall of the artery 15 and as a result do not interfere with the blood flow through the artery 15. The cylindrical elements 12 of stent 10 which are pressed into the wall of the artery 15 will eventually be covered with endothelial cell growth which further minimizes blood flow interference. The undulating portion of the cylindrical sections 12 provide good tacking characteristics to prevent stent movement within the artery. Furthermore, the closely spaced cylindrical elements 12 at regular intervals provide uniform support for the wall of the artery 15, and consequently are well adapted to tack up and hold in place small flaps or dissections in the wall of the artery 15 as illustrated in FIGS. 2 and 3.

[0023] FIG. 4 is an enlarged perspective view of the stent 10 shown in FIG. 1 with one end of the stent shown in an exploded view to illustrate in greater detail placement of interconnecting elements 13 between adjacent radially expandable cylindrical elements 12. Each pair of the interconnecting elements 13 on one side of a cylindrical element 12 are preferably placed to achieve maximum flexibility for a stent. In the embodiment shown in FIG. 4 the stent 10 has three interconnecting elements 13 between adjacent radially expandable cylindrical elements 12 which are 120 degrees apart. Each pair of interconnecting elements 13 on one end of a cylindrical element 12 are offset radially 60 degrees from the pair on the other side of the cylindrical element. The alternation of the interconnecting elements results in a stent which is longitudinally flexible in essentially all directions. Various configurations for the placement of interconnecting elements are possible, and several examples are illustrated schematically in FIGS. 7-9. However, as previously mentioned, all of the interconnecting elements of an individual stent should be secured to either the peaks or valleys of the undulating structural elements in order to prevent shortening of the stent during the expansion thereof.

[0024] FIG. 9 illustrates a stent wherein three interconnecting elements 13 are disposed between radially expandable cylindrical elements 12. The interconnecting elements 13 are distributed radially around the circumference of the stent at a 120 degree spacing. Disposing four or more interconnecting elements 13 between adjacent cylindrical elements 12 will generally give rise to the same considerations discussed above for two and three interconnecting elements.

[0025] FIG. 10 illustrates a stent structure in which the cylindrical elements are in serpentine patterns but out of phase with adjacent cylindrical elements. The particular pattern and how many undulations per unit of length around the circumference of the cylindrical element 12, or the amplitude of the undulations, are chosen to fill

particular mechanical requirements for the stent such as radial stiffness.

[0026] The number of undulations may be varied to accommodate placement of interconnecting elements 13, at the peaks of the undulations as shown in FIG. 10.

[0027] The stent 10 of the present invention can be made in many ways. However, the preferred method of making the stent is to coat a thin-walled tubular member, such as stainless steel hypotubing with a material which is resistive to chemical etchants and then to remove portions of the coating to expose underlying hypotubing which is to be removed but to leave coated portions of the hypotubing in the desired pattern for the stent so that subsequent etching will remove the exposed portions of the metallic tubing, but will leave relatively untouched the portions of the metallic tubing which are to form the stent. The coated portion of the metallic tube is in the desired shape for the stent. An etching process avoids the necessity of removing burrs or slag inherent in conventional or laser machine processes. It is preferred to remove the etchant-resistive material by means of a machine-controlled laser as illustrated schematically in FIG. 6.

[0028] A coating is applied to a length of tubing which, when cured is resistive to chemical etchants. "Blue Photoresist" made by the Shipley Company in San Jose, California, is an example of a suitable commercially available photolithographic coating. The coating is preferably applied by electrophoretic deposition.

[0029] To ensure that the surface finish is reasonably uniform, one of the electrodes used for the electrochemical polishing is a doughnut-shaped electrode which is placed about the central portion of the tubular member.

[0030] The tubing may be made of any suitable biocompatible material such as stainless steel, titanium, tantalum, superelastic NiTi alloys and even high strength thermoplastic polymers. The stent diameter is very small, so the tubing from which it is made must necessarily also have a small diameter. Typically the stent has an outer diameter on the order of about 1.5mm (0.06 inch) in the unexpanded condition, the same outer diameter of the hypotubing from which it is made, and can be expanded to an outer diameter of 2.5mm (0.1 inch) or more. The wall thickness of the hypotubing is about 0.076 mm (0.003 inch). In the instance when the stent is plastic, it has to be heated within the arterial site where the stent is expanded to facilitate the expansion of the stent. Once expanded, it is cooled to retain its expanded state. The stent may be conveniently heated by heating the fluid within the balloon or by heating the balloon directly by a suitable system such as disclosed in US-A-5,114,423 entitled "Dilation Catheter Assembly with Heated Balloon".

[0031] The stent may also be made of materials such as superelastic NiTi alloys such as described in US-A-5,411,476 entitled "Super-Elastic Guiding Member for Advancing Catheter".

[0032] In this case the stent would be formed full size

but deformed (e.g. compressed) into a small diameter onto the balloon of the delivery catheter to facilitate transfer to a desired intraluminal site. The stress induced by the deformation transforms the stent from a martensite phase to an austenite phase and upon release of the force, when the stent reaches the desired intraluminal location, allows the stent to expand due to the transformation back to the martensite phase.

[0033] Referring to FIG. 6, the coated tubing 21 is put in a rotatable collet fixture 22 of a machine controlled apparatus 23 for positioning the tubing 21 relative to a laser 24. According to machine-encoded instructions, the tubing 21 is rotated and moved longitudinally relative to the laser 24 which is also machine controlled.

[0034] The laser selectively removes the etchant-resistive coating on the tubing by ablation and a pattern is formed such that the surface of the tube that is to be removed by a subsequent chemical etching process is exposed. The surface of the tube is therefore left coated in the discrete pattern of the finished stent.

[0035] A presently preferred system for removing the coating on the tubing includes the use of an 80 watt CO<sub>2</sub> laser, such as Coherent Model 44, in pulse mode (0.3 mS pulse length); 48 mA key current and 48 W key power with 0.75 W average power; at 100 Hz; Anorad FR=10; 1680 Pa; (12.5 Torr); with no assist gas. Low pressure air is directed through the fine focus head to ensure that no vapor contacts the lens. The assist gas jet assembly on the laser unit may be removed to allow

[0036] a closer proximity of the fine focus head and the collet fixture. Optimum focus is set at the surface of the tubing. Cured photoresist coating readily absorbs the energy of the CO<sub>2</sub> wavelength, so that it can be readily removed by the laser. A coated 9.1 cm (4 inch) length of 1.5 mm (0.06 inch) stainless steel tubing is preferred and four stents can be patterned on the length of tubing. Three tabs or webs between stents provide good handling characteristics for the tubing after the etching process.

[0037] The process of patterning the resistive coating on the stent is automated except for loading and unloading the length of tubing. Referring again to FIG. 6 it may be done, for example, using a CNC opposing collet fixture 22 for axial rotation of the length of tubing, in conjunction with the CNC X/Y table 25 to move the length of tubing axially relative to a machine controlled laser as described. The entire space between collets can be patterned using the CO<sub>2</sub> laser set-up of the foregoing example. The program for control of the apparatus is dependent on the particular configuration used and the pattern to be ablated in the coating, but is otherwise conventional.

[0038] This process makes possible the application of present photolithography technology in manufacturing the stents. While there is presently no practical way to mask and expose a tubular photoresist-coated part of the small size required for making intravascular stents, the foregoing steps eliminate the need for conventional masking techniques.

[0037] After the coating is thus selectively ablated, the tubing is removed from the collet fixture 22. Next, wax such as ThermoCote N-4 is heated to preferably just above its melting point, and inserted into the tubing under vacuum or pressure. After the wax has solidified upon cooling, it is reheated below its melting point to allow softening, and a small diameter stainless steel shaft is inserted into the softened wax to provide support. The tubing is then etched chemically in a conventional manner. After cutting the tabs connecting the stents any surface roughness or debris from the tabs is removed. The stents are preferably electrochemically polished in an acidic aqueous solution such as a solution of ELECTRO-GLO #300, sold by ELECTRO-GLO CO., Inc., in Chicago, IL, which is a mixture of sulfuric acid, carboxylic acids, phosphates, corrosion inhibitors and a biodegradable surface active agent. The bath temperature is maintained at about 43 to 57 degrees centigrade (about 110-135 degrees F.) and the current density is about 0.06 to 2.3 amps/cm<sup>2</sup> (about 0.4 to about 1.5 amps per in<sup>2</sup>). Cathode to anode area should be at least about two to one. The stents may be further treated if desired, for example by applying a biocompatible coating.

[0038] While the invention has been illustrated and described herein in terms of its use as an intravascular stent, it will be apparent to those skilled in the art that the stent can be used in other instances such as to expand prostatic urethras in cases of prostate hyperplasia. Other modifications and improvements can be made without departing from the scope of the invention.

### Claims

1. A longitudinally flexible stent (10) comprising a plurality of cylindrically shaped elements (12) having an undulating pattern of peaks and valleys, the cylindrically shaped elements (12) being independently expandable in the radial direction and generally aligned on a common longitudinal axis such that, other than at an end of the stent (10), each cylindrically shaped element (12) has two adjacent cylindrically shaped elements (12) spaced in opposite axial directions, the undulating pattern of each of said cylindrically shaped elements (12) being out of phase with the undulating pattern of each of said adjacent cylindrically shaped elements (12) and each of said cylindrically shaped elements (12) being interconnected to one of said adjacent cylindrically shaped elements (12) at a location circumferentially displaced from the location at which said cylindrically shaped element (12) is interconnected to the other of said adjacent cylindrically shaped elements (12).
2. The stent (10) of claim 1, wherein the cylindrically shaped elements (12) are adapted to retain their expanded condition upon the expansion thereof.
3. The stent (10) of claim 1 or claim 2, wherein the radially expandable cylindrically shaped elements (12), in an unexpanded condition, have an axial length which is less than their diameter.
4. The stent (10) of any preceding claim, wherein each radially expandable cylindrically shaped element (12) is formed of a structural member which, in cross-section, has an aspect ratio of less than two to one.
5. The stent (10) of claim 4, wherein the structural member is formed of a biocompatible material selected from the group consisting of stainless steel, tungsten, tantalum, superelastic NiTi alloys and thermoplastic polymers.
6. The stent (10) of any preceding claim, wherein the circumferential displacement of the locations at which the cylindrically shaped elements (12) are interconnected is of equal magnitude.
7. The stent (10) of any preceding claim, wherein adjacent cylindrically shaped elements (12) are interconnected at up to four locations.
8. The stent (10) of any preceding claim, wherein the stent (10) is formed from a single piece of tubing (21).
9. The stent (10) of claim 11, wherein adjacent cylindrically shaped elements (12) are interconnected at either the peaks or the valleys of the undulating structural members.
10. The stent (10) of claim 1, wherein the stent (10) is coated with a biocompatible coating.
11. A kit comprising:
  - (a) an elongated stent delivery catheter (11) having proximal and distal extremities, and an expandable member (14) on the distal extremity; and
  - (b) a longitudinally flexible stent (10) which is adapted to be slidably mounted on to the expandable member (14) of said catheter (11) and comprising a plurality of cylindrically shaped elements (12) having an undulating pattern of peaks and valleys, the cylindrically shaped elements (12) being independently expandable in the radial direction and generally aligned on a common longitudinal axis such that, other than at an end of the stent (10), each cylindrically shaped element (12) has two adjacent cylindrically shaped elements (12) spaced in opposite axial directions, the undulating pattern of each of said cylindrically shaped elements (12) being out of phase with the undulating pattern of each of said adjacent cylindrically shaped elements (12) and each of said cylindrically shaped elements (12) being interconnected to one of said adjacent cylindrically shaped elements (12) at a location circumferentially displaced from the location at which said cylindrically shaped element (12) is interconnected to the other of said adjacent cylindrically shaped elements (12).

ments (12) being out of phase with the undulating pattern of each of said adjacent cylindrically shaped elements (12) and each of said cylindrically shaped elements (12) being interconnected to one of said adjacent cylindrically shaped elements (12) at a location circumferentially displaced from the location at which said cylindrically shaped element (12) is interconnected to the other of said adjacent cylindrically shaped elements (12).

#### Patentansprüche

1. Längsflexibler Stent (10), umfassend eine Mehrzahl zylindrisch geformter Elemente (12) mit einem Wellenmuster von Gipfeln und Tälern, wobei die zylindrisch geformten Elemente (12) in der radialen Richtung unabhängig aufweitbar sind und allgemein auf einer gemeinsamen Längsachse ausgerichtet sind, so daß, außer an einem Ende des Stents (10), jedes zylindrisch geformte Element (12) zwei benachbarte, in entgegengesetzte Axialrichtungen mit Abstand angeordnete zylindrisch geformte Elemente (12) aufweist, wobei das Wellenmuster jedes der zylindrisch geformten Elemente (12) außer Phase mit dem Wellenmuster jedes der benachbarten zylindrisch geformten Elemente (12) ist und jedes der zylindrisch geformten Elemente (12) mit einem der benachbarten zylindrisch geformten Elemente (12) an einer Stelle verbunden ist, die von der Stelle, an der das zylindrisch geformte Element (12) mit dem andern der benachbarten zylindrisch geformten Elemente (12) verbunden ist, in Umfangsrichtung versetzt ist.
2. Stent (10) nach Anspruch 1, wobei die zylindrisch geformten Elemente (12) dazu ausgelegt sind, nach dem Aufweiten derselben ihren aufgeweiteten Zustand zu behalten.
3. Stent (10) nach Anspruch 1 oder Anspruch 2, wobei die radial aufweitbaren zylindrisch geformten Elemente (12) im nicht aufgeweiteten Zustand eine axiale Länge haben, die kleiner ist als ihr Durchmesser.
4. Stent (10) nach einem der vorhergehenden Ansprüche, wobei jedes radial aufweitbare zylindrisch geformte Element (12) aus einem Strukturelement gebildet ist, das im Querschnitt ein Aspektverhältnis von weniger als zwei zu eins hat.
5. Stent (10) nach Anspruch 4, wobei das Strukturelement aus einem biokompatiblen Material gebildet ist, gewählt aus der Gruppe, bestehend aus rostfreiem Stahl, Wolfram, Tantal, superelastischen NiTi-Legierungen und thermoplastischen Polymeren.
6. Stent (10) nach einem der vorhergehenden Ansprüche, wobei der Umfangsversatz der Stellen, an denen die zylindrisch geformten Elemente (12) miteinander verbunden sind, gleich groß ist.
7. Stent (10) nach einem der vorhergehenden Ansprüche, wobei benachbarte zylindrisch geformte Elemente (12) an bis zu vier Stellen miteinander verbunden sind.
8. Stent (10) nach einem der vorhergehenden Ansprüche, wobei der Stent (10) aus einem einzigen Rohrstück (21) gebildet ist.
9. Stent (10) nach Anspruch 11, wobei benachbarte zylindrisch geformte Elemente (12) an den Gipfeln oder Tälern der Wellenstrukturelemente miteinander verbunden sind.
10. Stent (10) nach Anspruch 1, wobei der Stent (10) mit einer biokompatiblen Beschichtung beschichtet ist.
11. Satz, umfassend:
  - (a) einen langgestreckten Stent-Einführkatheter (11) mit einem proximalen Ende und einem distalen Ende und einem aufweitbaren Element (14) an dem distalen Ende; und
  - (b) einen längsflexiblen Stent (10), der dazu ausgelegt ist, verschiebbar an dem aufweitbaren Element (14) des Katheters (11) angebracht zu werden und der eine Mehrzahl zylindrisch geformter Elemente (12) mit einem Wellenmuster von Gipfeln und Tälern umfaßt, wobei die zylindrisch geformten Elemente (12) in der radialen Richtung unabhängig aufweitbar sind und allgemein auf einer gemeinsamen Längsachse ausgerichtet sind, so daß, außer an einem Ende des Stents (10), jedes zylindrisch geformte Element (12) zwei benachbarte, in entgegengesetzte Axialrichtungen mit Abstand angeordnete zylindrisch geformte Elemente (12) aufweist, wobei das Wellenmuster jedes der zylindrisch geformten Elemente (12) außer Phase mit dem Wellenmuster jedes der benachbarten zylindrisch geformten Elemente (12) ist und jedes der zylindrisch geformten Elemente (12) mit einem der benachbarten zylindrisch geformten Elemente (12) an einer Stelle verbunden ist, die von der Stelle, an der das zylindrisch geformte Element (12) mit dem andern der benachbarten zylindrisch geformten Elemente (12) verbunden ist, in Umfangsrichtung versetzt ist.

**Revendications**

1. Dilatateur (10) flexible longitudinalement, comprenant une pluralité d'éléments de forme cylindrique (12) ayant un motif onduleux de crêtes et de creux, les éléments de forme cylindrique (12) étant indépendamment extensibles dans la direction radiale et étant généralement alignés sur un axe longitudinal commun de telle sorte que, ailleurs qu'à une extrémité du dilatateur (10), chaque élément de forme cylindrique (12) ait deux éléments de forme cylindrique (12) espacés dans des directions opposées, le motif onduleux de chacun desdits éléments de forme cylindrique (12) étant déphasé par rapport au motif onduleux de chacun desdits éléments de forme cylindrique (12) contigus et chacun desdits éléments de forme cylindrique (12) étant raccordé à l'un desdits éléments de forme cylindrique (12) contigus, en une position décalée dans la direction circonférentielle de la position à laquelle ledit élément de forme cylindrique (12) est raccordé à l'autre desdits éléments de forme cylindrique (12) contigus.
2. Dilatateur (10) selon la revendication 1, dans lequel les éléments de forme cylindrique (12) sont conçus pour conserver leur état dilaté lors de leur dilatation.
3. Dilatateur (10) selon la revendication 1 ou la revendication 2, dans lequel les éléments de forme cylindrique (12) dilatables radialement ont, dans un état non dilaté, une longueur axiale qui est inférieure à leur diamètre.
4. Dilatateur (10) selon l'une quelconque des revendications précédentes, dans lequel chaque élément de forme cylindrique (12) dilatable radialement est formé d'un élément structurel qui, en section transversale, à un rapport d'aspect inférieur à 2 : 1.
5. Dilatateur (10) selon la revendication 4, dans lequel l'élément structurel est formé d'un matériau biocompatible choisi dans un groupe comprenant l'acier inoxydable, le tungstène, le tantal, les alliages au NiTi super élastiques et les polymères thermoplastiques.
6. Dilatateur (10) selon l'une quelconque des revendications précédentes, dans lequel le déplacement circonférentiel des positions auxquelles les éléments de forme cylindrique (12) sont interconnectés est de même valeur.
7. Dilatateur (10) selon l'une quelconque des revendications précédentes, dans lequel les éléments de forme cylindrique (12) contigus sont interconnectés en un nombre de positions allant jusqu'à quatre.
8. Dilatateur (10) selon l'une quelconque des revendications précédentes, caractérisé en ce qu'il est formé d'un seul morceau de tube (21).
9. Dilatateur (10) selon la revendication 1, dans lequel les éléments de forme cylindrique (12) contigus sont raccordés aux crêtes ou bien aux creux des éléments structurels onduleux.
10. Dilatateur (10) selon la revendication 1, caractérisé en ce qu'il est enduit d'un revêtement biocompatible.
11. Ensemble comprenant :
- (a) un long cathéter de mise en place de dilatateur (11) ayant une extrémité proximale et une extrémité distale, et un élément dilatable (14) sur l'extrémité distale ; et
- (b) un dilatateur (10) flexible dans la direction longitudinale, qui est conçu pour être monté coulissant sur l'élément dilatable (14) dudit cathéter (11) et comprenant une pluralité d'éléments de forme cylindrique (12) ayant un motif onduleux de crêtes et de creux, les éléments de forme cylindrique (12) étant indépendamment dilatables dans la direction radiale et étant généralement alignés sur un axe longitudinal commun de telle sorte que, ailleurs qu'à une extrémité du dilatateur (10), chaque élément de forme cylindrique (12) ait deux éléments de forme cylindrique (12) espacés dans des directions opposées, le motif onduleux de chacun desdits éléments de forme cylindrique (12) étant déphasé par rapport au motif onduleux de chacun desdits éléments de forme cylindrique (12) contigus et chacun desdits éléments de forme cylindrique (12) étant raccordé à l'un desdits éléments de forme cylindrique (12) contigus, en une position décalée dans la direction circonférentielle de la position à laquelle ledit élément de forme cylindrique (12) est raccordé à l'autre desdits éléments de forme cylindrique (12) contigus.

FIG. 1

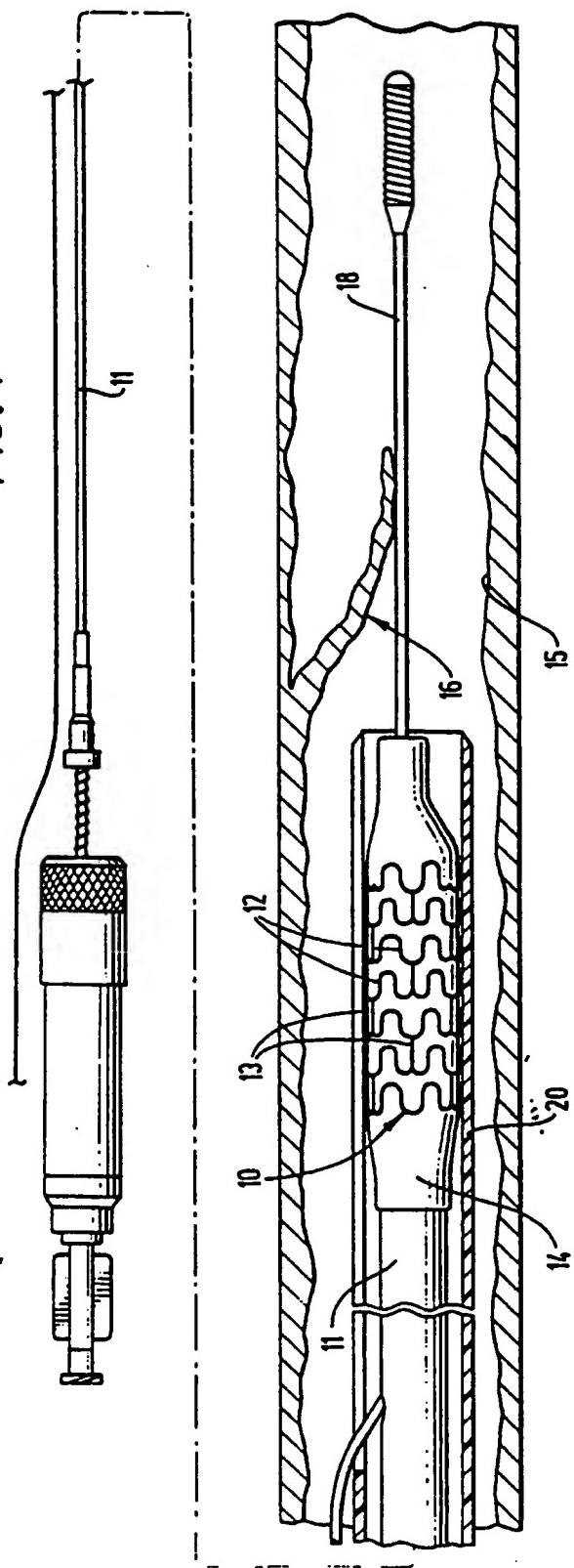
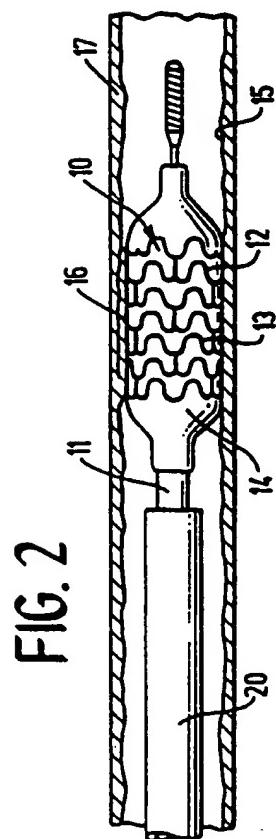
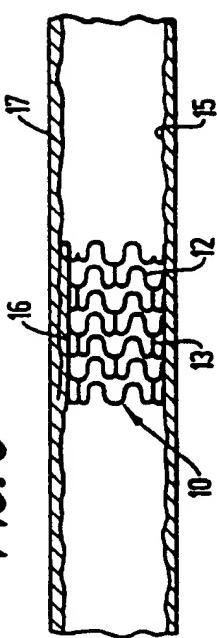


FIG. 3



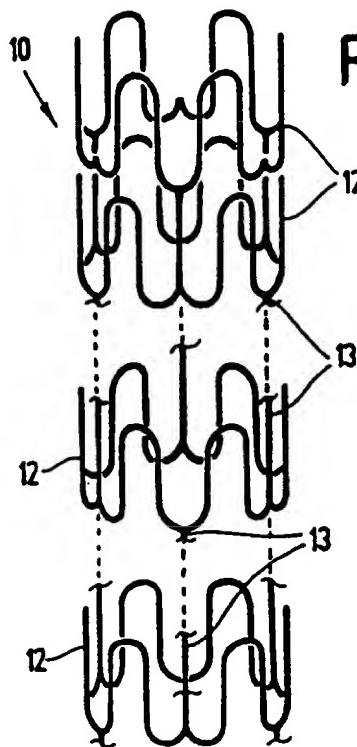


FIG. 4

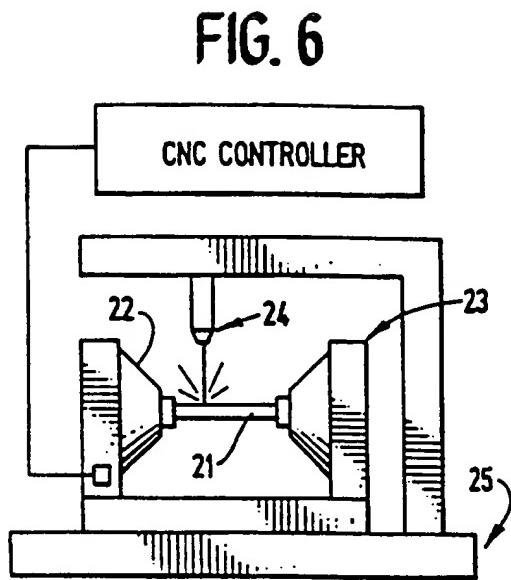


FIG. 6

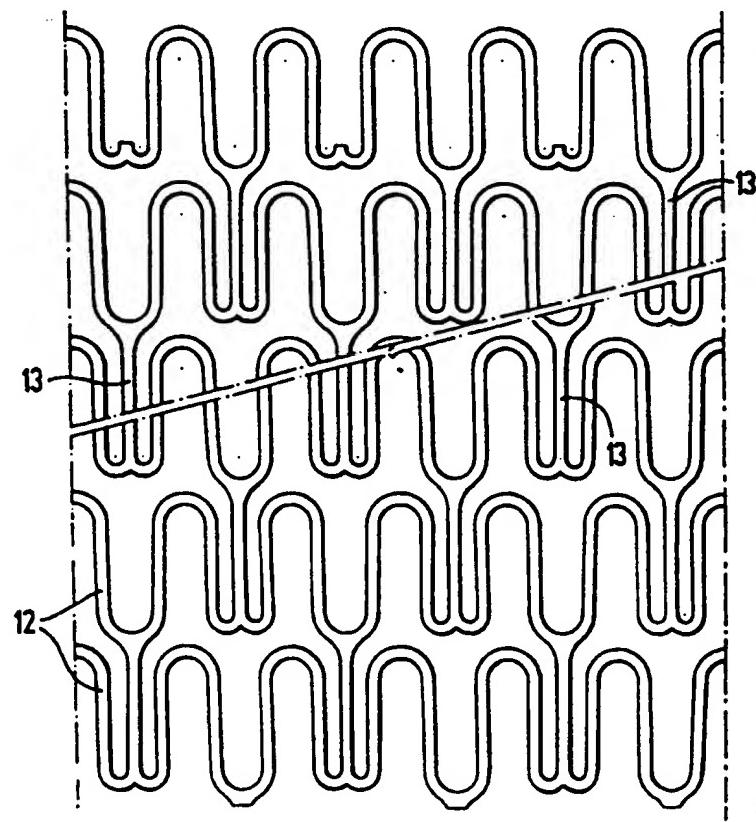


FIG. 5

FIG. 7

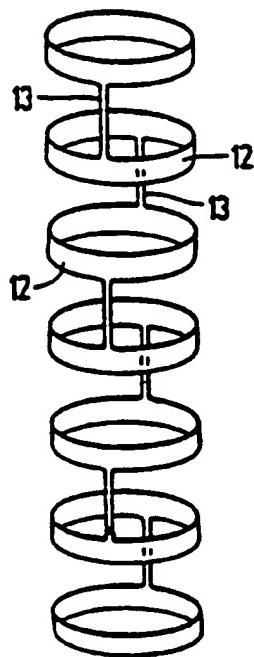


FIG. 8

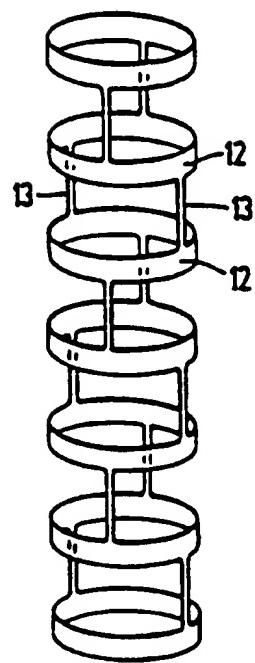


FIG. 9

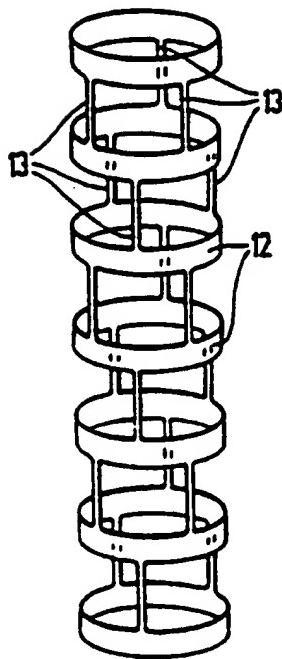


FIG. 10

